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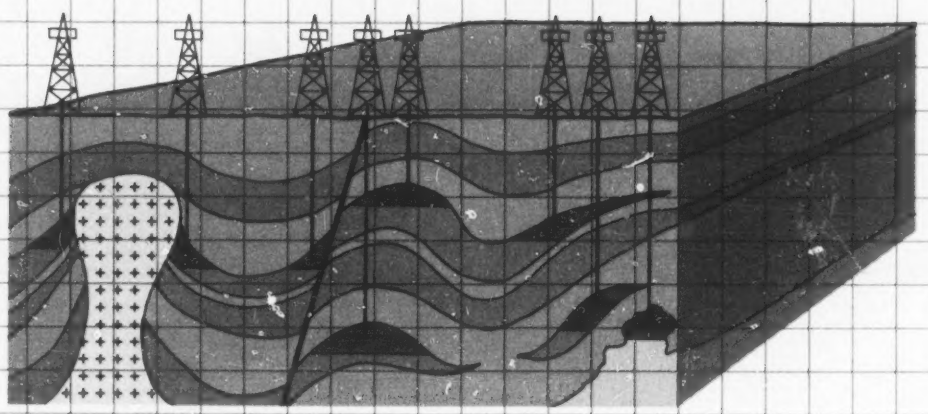
EXXON BACKGROUND SERIES

How Much Oil and Gas?



MAY 1982

A background paper prepared by the Public Affairs Department of
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How Much Oil and Gas?

Table of Contents

Chapter	*Title*	*Page*
1	**Introduction**	2
2	**Terms and Definitions**	3
	Requisites for Recoverable Petroleum to Exist in a Sedimentary Basin	4
	U.S. Companies Required to Report Proved Reserves	6
3	**Methods of Estimation**	6
	Estimating Discovered Resources	6
	Estimating Undiscovered Potential	7
4	**Resource Estimates**	9
	World Oil and Gas Resource Base	9
	Discovered Reserves	11
	Distribution of Undiscovered Potential	13
	Outlook for Discovery Rates	14
	Improved Recovery Prospects	15
	Other Hydrocarbon Resources	16
5	**Summary**	17

List of Illustrations and Tables

Fig.		
1	Sedimentary Basin	3
2	Types of Oil and Gas Accumulations	4
3	World Oil and Gas Resources	5
4	Principal Sedimentary Basins	8
5	World Total Petroleum Reserves Potential	9
6	World Oil Discoveries	14
7	World Gas Discoveries	15
Table		
1	World Oil and Gas Resource Base	10
2	Cumulative Crude Oil Production of Leading Countries	10
3	Estimated Proved Crude Oil Reserves of Leading Countries	11
4	Estimated Proved Crude Oil Reserves by Groups of Countries	12
5	Estimated Proved Natural Gas Reserves of Leading Countries	12
6	Estimated Proved Natural Gas Reserves by Groups of Countries	13

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1 Introduction

The goal of this booklet is increased public understanding of the petroleum resources that remain in the world after more than a century of exploration and production.

Everyone recognizes that crude oil and natural gas exist in finite amounts, but no one really knows how much of either remains. Since E.L. Drake drilled his first well in 1859, a vast industry has been established and oil has become the world's dominant fuel. But petroleum geologists freely admit that definitive knowledge about the resource base that made this growth possible remains elusive.

Nevertheless, much has been learned and is being learned everyday about the earth and about the oil and gas fields already discovered. With this has come an improved ability to estimate the amount, location, and recoverability of the petroleum that remains to be found. Such information is important because it is widely assumed that oil and gas will together supply more than half the world's energy for the rest of this century, and a substantial portion for many years thereafter. If it were not believed that enough recoverable petroleum is left in the ground to make this feasible, major changes in investment plans, government policies, and the direction of scientific research would be needed.

At any given time, the amount of oil and gas available for consumption depends primarily on two factors: the producibility of already discovered reserves and the production policies of governments in the countries where those reserves exist. Over the long run, however, it is the amount of recoverable oil and gas left in the ground, including those volumes as yet undiscovered, that will be decisive. It is this, along with the economic factors influencing petroleum's supply and demand, that will determine how long the world can rely on crude oil and natural gas and how soon it must develop other sources of energy.

Estimates of the remaining petroleum resource base vary widely. Experts disagree about the size and producibility of individual reservoirs and about the total national and world reserves associated with already discovered fields. They are even further apart when assessing the world's undiscovered potential. This is not surprising when it is remembered that they are making judgments —frequently educated guesses—about hydrocarbons contained in porous rocks many thousands of feet under the earth's surface. Often, they have little more to go on than the data from a few widely dispersed 8-inch diameter holes in existing fields—and still less information in the case of fields expected to be discovered in the future.

The weight of informed opinion is not only that much petroleum remains to be discovered, but also that new reserves will be harder to find and more difficult and expensive to produce. There are limited prospects for finding additional giant fields such as those currently being worked in the Middle East.

Greater awareness of the ultimate limits of the world's petroleum and of the sharply increased costs of finding new supplies has underscored the need to make the most of known resources. For this reason, more attention than ever is now being focused on "improved recovery" from discovered fields. Such methods will add to usable energy supplies—perhaps significantly.

This booklet describes the elements that make up the oil and gas resource base, gives estimates of their magnitude, and explains how these estimates are developed. In the process, it also defines some terms that have given rise to confusion. "Proved," "probable," and "potential" reserves are not the same thing, nor are "reserves" the same as "resources," though all have sometimes been used interchangeably.

2 Terms and Definitions

Simply stated, the petroleum geologists' challenge is to identify areas where oil and gas are likely to exist in quantities large enough to justify the costs of finding and producing them. The starting point is a *sedimentary basin*, the basic regional geologic unit in which petroleum can exist (Figure 1). A basin is a subsurface area where layers or beds of sedimentary materials —clays or muds (shales), sandstones, or limestones—were deposited over millions of years.

The more promising basins for petroleum are those that originally formed in ancient seas or lakes whose waters contained countless tiny plants and animals. As these died, they were absorbed in the mud on the bottom, subjected over time to heat and pressure, and gradually transformed into petroleum. With the further passage of time, some of this petroleum was squeezed out of the shales and into cracks and pore spaces in adjacent sandstone or limestone beds. When this process took place during or just after vertical or horizontal movements of the earth's crust, a fraction of the oil and gas accumulated in localized traps or reservoirs—the fields which the industry seeks today. (See box on page 4.)

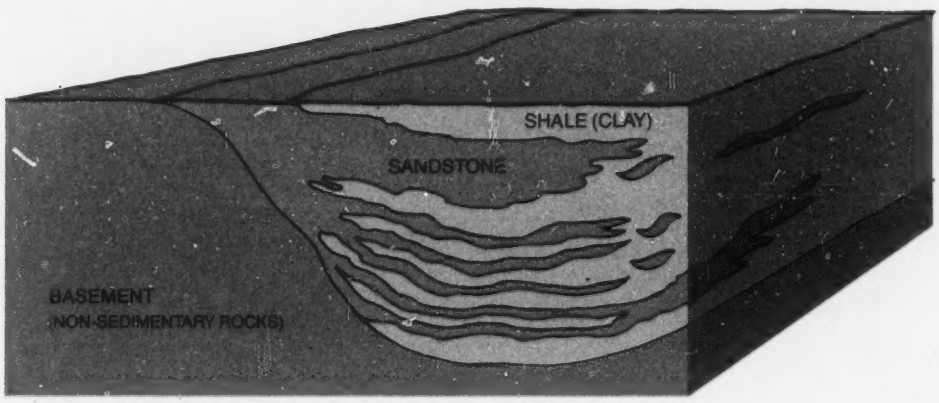
Oil and gas reservoirs are not simply big subterranean caves or caverns. They are sandstone or limestone beds—often only a few feet thick but sometimes extending for miles—in whose pores and cracks oil and gas have been stored for eons. These hydrocarbons must move fairly long distances through those tiny openings in order to reach a few small drainage points (the wells) and be produced. It normally takes 10 to 30 years to fully recover a field's reserves—a tiny fraction of the time it took for its formation.

It would be interesting to know just how much oil and gas was originally in place in each trap. However, use of such figures would be misleading because typically only a portion of the oil in a given trap—often much less than half—is recoverable and, therefore, available to run our cars or heat our homes.

A more practical concept, therefore, is petroleum *resources*, which is defined as all the oil and gas believed to be eventually recoverable, by means of known or expected technologies, out of the total volumes in place. Some of these resources have already been found and are referred to as *discovered resources*. Those expected to be found in the

Figure 1

Sedimentary Basin



The Requisites for Recoverable Petroleum to Exist in a Sedimentary Basin

For oil and gas to have accumulated in a reservoir and to be recoverable, all of the following had to be present:

> A *source rock*, such as a shale, which was formed millions of years ago when layers of mud containing billions of microscopic animals and plants sank to the bottom of a sea or lake. Over time, as additional layers of sediments built up on top of them, these muds were subjected to heat and pressure, causing them to solidify and form shales. This process also led to the decomposition of the organisms deposited with the mud into compounds of hydrogen and carbon that we now know as petroleum.

> A *reservoir rock*, such as a sandstone or limestone layer, which was in contact with source rocks so it could receive petroleum that was squeezed out of the source rocks as they were compressed by overlying sediments. The reservoir rock had to be porous—have cracks and open spaces between its grains—to provide a place to store the petroleum received from the source rocks. It also had to be permeable so that the oil and gas could move through it.

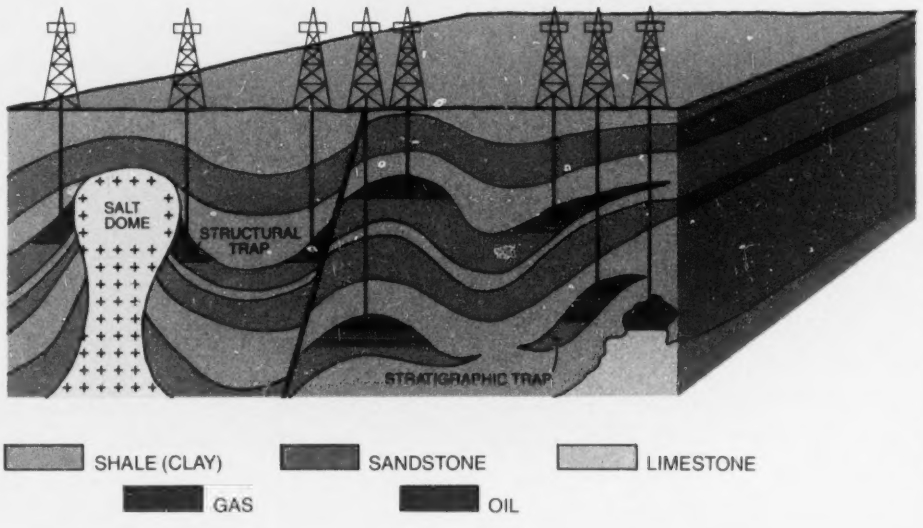
> A *trap* (Figure 2), where oil and gas—which are lighter than the water that is also in the reservoir—have accumulated. There are two general types of traps: *structural* traps, formed by the folding or faulting of the reservoir rock layers, and *stratigraphic* traps, created when layers of porous, permeable reservoir rocks are sealed off by superimposed impermeable beds.

> A *seal*, which is the dense rock that overlies the trap and prevents the petroleum liquids and gases from escaping.

Not only must all these features have been present; they also must have been properly related in time. The source rock had to be in contact with the reservoir rock after the organic matter was transformed into hydrocarbons so that they could be squeezed out of the shales and into the reservoirs. Similarly, the traps (and the seals) had to exist at the time the hydrocarbons were being forced into the reservoir rocks, in order to limit the movement of the oil and gas and so cause them to accumulate in what we today call oil and gas fields.

Figure 2

Types of Oil and Gas Accumulations



Although caused by different natural phenomena, all types of hydrocarbon traps perform the same role: providing a site for the subsurface accumulation of oil and gas and, thereby, creating the fields that are sought by the drill. This simplified sketch shows examples of major traps.

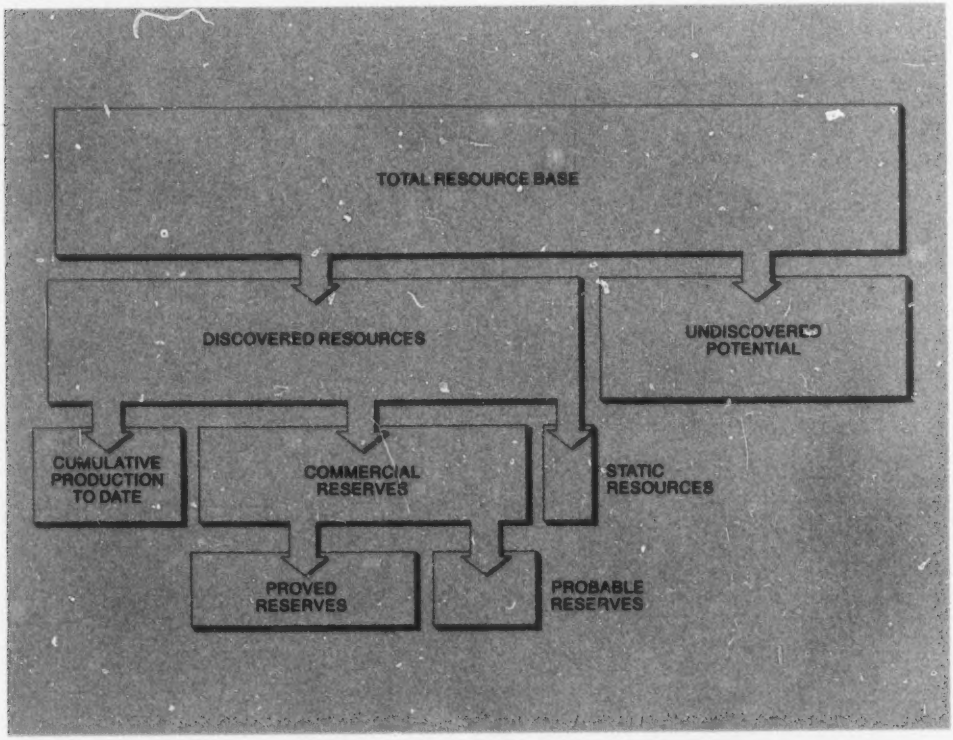
future are *undiscovered potential* resources. The *total resource base* is the sum of the two, as depicted in Figure 3. The specialist's perception of how much is recoverable is derived from a mixed bag of knowledge, ranging all the way from some relatively firm data to much that is highly speculative. Consequently, it changes with time, in response to new geological information, improvements in exploration and recovery technology, and anticipated changes in price trends.

A more limited but also elusive concept is that of *commercial reserves*, the segment of discovered resources that is thought to be recoverable at current or forecast prices. Of these, *proved* reserves—those whose existence is known with a high degree of confidence and which are commercially producible—are the most widely discussed. This is because petroleum companies regularly report their proved reserves to governments and shareholders. (See box on page 6.) *Probable* reserves are those whose existence is less well known and which are expected to be commercial in the future. The non-commercial portion of the discovered resources is called *static* resources. If prices rise, or if a remote area is developed because other fields are found nearby and a pipeline is built, or if drilling indicates a higher reserves volume than originally thought—then a static resource will become commercial and will move into the proved or probable reserves category.

Unfortunately, there is no universally accepted classification system for petroleum resource concepts. The terms used in this booklet are defined in accordance with the system employed by Exxon. Others may use fewer or more categories and may give them somewhat different names. No matter what classification system is used, however, the geologic and economic distinctions are not—and cannot be—precise. What is geologically known and/or commercially feasible changes with time and circumstances.

Figure 3

World Oil and Gas Resources



U.S. Companies Required To Report Proved Reserves

Current Federal securities law regulations require U.S. oil and gas producing companies registered with the Securities and Exchange Commission to include in their annual reports to shareholders estimates of the amount and value of their proved reserves in the ground. The purpose is to give the public—and particularly investors and potential investors—a better understanding of each company's worth and a better means of comparing one company with another.

The goal is worthy. But the fact that such information is published as a supplement to financial statements gives a misleading impression of its accuracy. Estimates of proved reserves are inherently uncertain, no matter how much effort goes into them. Estimates of the value of these reserves are even less accurate because production will occur over a long period during which significant changes may occur: in oil and gas prices, in production costs and production capabilities, and in competitive sources of energy.

Confusion may also arise from the exclusion of other, less certain classes of oil and gas resources (probable reserves, static resources, and undiscovered potential) for which formal reporting is not required.

In some cases, the latter might turn out to be more important than the proved reserves. For example, when a new field is discovered, several years may be required before the field size, its producing characteristics, and its recoverable reserves are sufficiently defined for it to be considered commercial. And even then it frequently is only possible to classify as proved that part of the field which is in the area tested by the original discovery well and subsequent successful follow-up wells. Additional volumes are usually added to proved reserves in succeeding years, as the rest of the field is confirmed and as the prospects for improving recovery are evaluated. Thus, a dilemma is posed: reporting only proved reserves tends to understate a company's petroleum assets in the ground—but including other categories would introduce still further elements of uncertainty.

3 Methods of Estimation

Geologists and reservoir engineers understandably have a better idea of how much oil and gas remain in fields already discovered than of how much is likely to be contained in fields yet to be discovered. This is because discovered fields always yield some information on which to base reserves estimates whereas projections of undiscovered potential are necessarily much more speculative. Not surprisingly, the methods used to estimate discovered resources and undiscovered potential differ considerably.

Estimating Discovered Resources

After more than a century of petroleum exploration and production, the industry has developed a fairly substantial data base that can be used to estimate both commercial reserves and static resources for existing fields. Most of the world's major oil and gas fields have been extensively analyzed by the operators, and information on many of them is available publicly in technical journals. Geologic and engineering studies have also been published on many smaller fields in the United States and some other countries.

Depending on the amount and quality of information available, three general approaches are used in estimating the amount of oil and gas recoverable from an existing field:

- *Extrapolations*, based on a field's past production. Extrapolation techniques are primarily applicable to the already-drilled and producing portions of a field. Factors taken into account include the production history and decline rates, the existence of undeveloped but potentially productive zones elsewhere in the field, the possibilities for enhanced recovery, and any constraints that may have inhibited past production.

> *Theoretical calculations*, based on an existing field's geological and geophysical characteristics. These are especially useful for forecasting production from the yet-to-be-drilled portions of a field. They involve such data as the field's area and the degree to which it is delineated; average thickness of the producing formations; porosity of the reservoir rocks; reservoir pressure and temperature; permeability of the rocks and characteristics of the oil, gas, and water in them; nature of the reservoir energy originally available to move the oil and gas into the well bores; and probable susceptibility of the reservoir to various methods of supplementing the original sources of energy.

> *Comparisons* with other, similar fields for which more data are available. This approach is employed when the other two methods are not feasible—for example, in the case of a field which has not yet been developed or for which very little information is available. The assumption is that the new field will yield results like those of other, better-known fields which have comparable geological and/or reservoir characteristics.

Economic considerations determine how much of the discovered resources should be classified as commercial reserves. Questions to be answered about each field are: What capital expenditures will be required to initiate or complete development (a function of average production per well per day, the number of wells required, and anticipated well depths)? What will be the operating conditions (including accessibility, climate, weather conditions and, in the case of an offshore field, the depth of the water)? What quality oil will be produced (gravity and viscosity)? What is the outlook for oil and gas prices?

Usually, the published estimates of remaining reserves for already-discovered fields are in reasonably close agreement. Differences are due mainly to variations in the estimates of how much is likely to be obtained from application of improved recovery methods.

The bases for estimating undiscovered potential—and for identifying locations for exploration—are geologic studies of the world's sedimentary basins (Figure 4, page 8). Geologists have identified approximately 600 sedimentary basins scattered throughout the world. About 160 of these are known to be productive or capable of production. Roughly 240 others have been explored to some degree—many only slightly—without the discovery of producible reserves. Another 100 are still essentially unexplored because of hostile physical conditions. The last 100 are judged to have very little chance of yielding petroleum, either because there is enough information on them to indicate that they simply lack the proper geologic characteristics or because they are located in environments beyond the reach of known or imagined technology.

Ultimately, of course, there is no substitute for the knowledge that comes from drilling exploratory wells. These are extremely costly, however, and, if undertaken indiscriminately, would make the discovery of hydrocarbons prohibitively expensive. For this reason, various supplementary techniques have been developed to improve exploration efficiency. These techniques, which utilize knowledge of the geological and geochemical principles that govern hydrocarbon occurrence, help to narrow the range of possible places where oil and gas may be found. They involve gathering and analyzing large quantities of data, including:

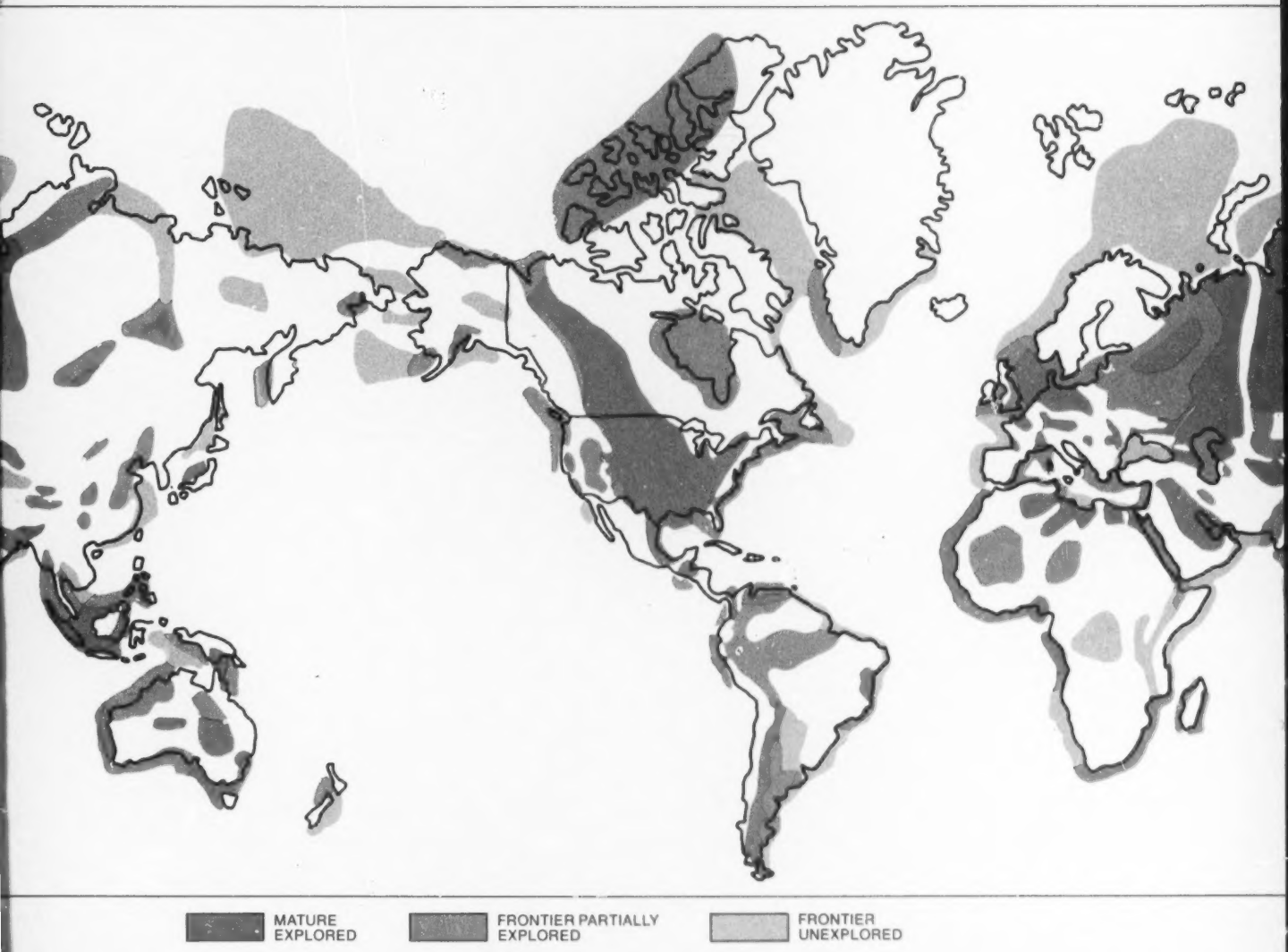
> Direct geological and geochemical data collected from surface rocks and exploratory wells.

> Indirect data from many sources, including seismic surveys (analyses of sonic wave reflections from underground rock layers), gravimetric and magnetic surveys (measurements of the effects of various rocks on the earth's gravity and magnetic fields), and photographs of the earth's surface from satellites and aircraft.

The use of computers to analyze such data has become an important factor in the search for oil. They make it possible to analyze more data in more ways, thus increasing the chances of finding subtle indications of petroleum reservoirs that otherwise might be overlooked.

Figure 4

Principal Sedimentary Basins

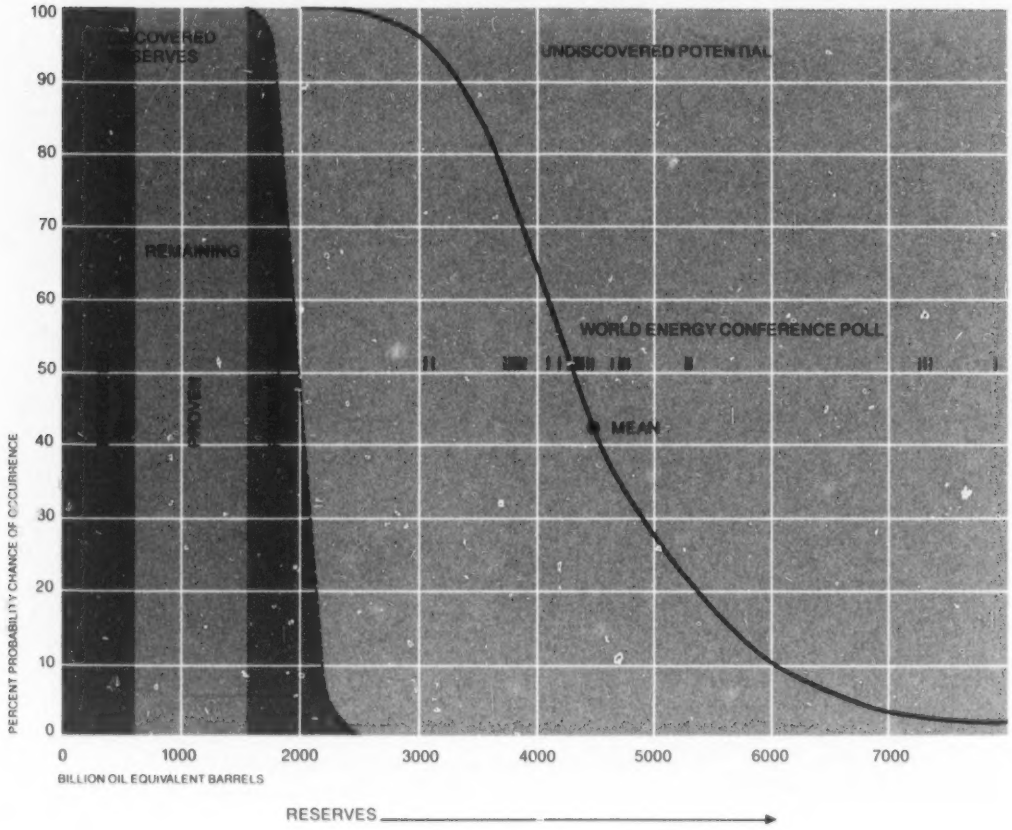


Even with these sophisticated analytical techniques, the assessment of undiscovered potential requires a great deal of informed judgment. When little information is available, the experts must rely principally on their interpretations of comparisons with better known basins that appear to have similar geologic characteristics. As exploration proceeds and the availability of geologic information increases, the quality of reserve calculations improves. But even in these circumstances, judgment is needed in deciding which data and calculation methods should be employed.

Because of the uncertainties in the assessment process, experts typically assign probabilities of occurrence to each of the various geologic factors which affect the existence and recovery of hydrocarbons. Such probabilities reflect the risk that the necessary geologic elements might not exist, as well as the imperfections in the data used. Putting these various assessments together yields an overall estimate of future undiscovered potential.

Figure 5

World Total Petroleum Reserves Potential



4 Resource Estimates

Given the ways in which petroleum was formed and stored over time, how much recoverable oil and gas is there in the world, and how is it distributed? What have been the historical trends of discoveries, what is the outlook for finding new oil and gas in the future, and what are the prospects for improving the recovery from existing fields?

World Oil and Gas Resource Base

Experts, as has been noted, do not agree on the answers. A good example was provided by the 1977 World Energy Conference (WEC), at which twenty-seven petroleum companies, government agencies and individual consultants submitted projections. These are shown in Figure 5. Estimates of the total oil and gas resource base—including what has been produced, the rest of what has already been discovered, and what is still undiscovered—ranged from about 3,000 to 7,000 billion barrels oil equivalent. (Oil equivalent means crude oil, plus natural gas expressed as its energy equivalent in oil, plus liquids removed from the gas.) Applying statistical analysis to those experts' views indicates the mean—or most likely—result to be around 4,500 billion barrels. It also shows a 95 percent probability that the resource base was at least 3,000 billion barrels but only a 5 percent probability that it could be as high as 6,500 billion barrels.

Table 1 provides a more recent estimate of the world's oil and gas resource base, compiled by Exxon from a variety of industry sources and divided into the categories defined earlier. These figures suggest that the total resource base is between 3,000 and 5,000 billion barrels oil equivalent.

While the more recent total is reasonably consistent with the WEC mean of 4,500 billion barrels, the figures in Table 1 differ significantly from the World Energy Conference data in the estimate of undiscovered potential: the new range is 1,000 to 2,500 billion barrels, compared with 1,000 to 6,500 billion barrels for the WEC. One reason for this is the additional information that has been obtained from the exploration results of the ensuing three or four years; another is the fact that the newer range reflects industry projections only, whereas the WEC survey included a number of non-industry respondents.

Table 1

World Oil and Gas Resource Base

(1981)

	*Billions of Barrels Oil Equivalent**
Remaining Proved Reserves	1000-1200
Probable Reserves	300-600
Total Remaining Commercial Reserves	1300-1800
Cumulative Production to Date	700
Total Resources Discovered to Date	2000-2500
Undiscovered Potential	1000-2500
Total Oil and Gas Resource Base	3000-5000

**Includes crude oil, natural gas expressed as its energy equivalent in oil, and liquids removed from the gas.*

Table 2

Cumulative Crude Oil Production of Leading Countries

As of July 1, 1981

Country	*Cumulative Production (Billions of Barrels)*	*Year of 1st Discovery*
U.S.	127	1859
U.S.S.R.	75	1873
Saudi Arabia*	44	1938
Venezuela	36	1914
Iran	30	1908
Kuwait*	22	1938
Iraq	16	1909
Libya	14	1959
Canada	10	1913
Indonesia	9	1906
Nigeria	9	1958
Mexico	8	1901
Abu Dhabi	6	1953
Algeria	6	1956
Argentina	4	1907
Qatar	3	1940

**Including 50% of Neutral Zone*

Source: Oil & Gas Journal.

Discovered Reserves

In the more than 120 years since the first oil well was drilled in Pennsylvania in 1859, the world's cumulative production has been about 700 billion barrels oil equivalent. That is around 30 percent of the more than 2,000 billion barrels which have been discovered to date, shown in Table 1.

Table 2 shows that the U.S. is the world leader in cumulative crude oil production, even though it no longer leads in current output. The U.S.S.R., where oil was discovered in 1873, is second in cumulative production; and Saudi Arabia, which had its first discovery in 1938, is third. Reliable data on cumulative natural gas production are not available for many countries. Indeed, historical gas production for the world probably will never be known accurately because an indeterminate, but surely large, amount of gas was flared without being measured in the years before there were markets for it, and before reservoir energy conservation practices were introduced. However, the U.S. is certainly the leader in cumulative gas production, just as it has been for oil, and the U.S.S.R. is undoubtedly second.

Proved oil reserves are the most important part of the resource base, at least for the short term, and are distributed quite unevenly among nations. As illustrated in Table 3, the reported totals for individual countries can rise or fall significantly over the years, depending on production and the timing of additions to reserves. Of the top ten countries, five are in the Middle East, including Saudi Arabia, which is first by a wide margin, and Kuwait, which is second. Saudi Arabia accounts for 25 percent of the total; the top five, 62 percent; and the top fifteen, 92 percent.

Table 3

Estimated Proved Crude Oil Reserves of Leading Countries

(Billions of barrels)

Rank	*Country*	*1/1/82*	*1/1/77*	*(Rank)*	*1/1/72*	*(Rank)*
1	Saudi Arabia*	167.9	113.2	(1)	157.5	(1)
2	Kuwait*	67.7	70.6	(3)	78.2	(2)
3	U.S.S.R.	63.0	78.1	(2)	75.0	(3)
4	Iran	57.0	63.0	(4)	55.5	(4)
5	Mexico	57.0	7.0	(14)	4.5	(19)
6	Abu Dhabi	30.6	29.0	(7)	18.9	(8)
7	U.S.	29.8	31.3	(6)	37.3	(5)
8	Iraq	29.7	34.0	(5)	36.0	(6)
9	Libya	22.6	25.5	(8)	25.0	(6)
10	Venezuela	20.3	15.3	(12)	13.9	(9)
11	P.R.C.	19.9	20.0	(9)	20.0	(7)
12	Nigeria	16.5	19.5	(10)	11.7	(11)
13	U.K.	14.8	16.8	(11)	5.0	(18)
14	Indonesia	9.8	10.5	(13)	10.4	(12)
15	Algeria	8.1	6.8	(15)	12.3	(10)
	Top 15	614.7	540.6		561.2	
	All others	56.0	58.4		70.7	
	World Total	670.7	599.0		631.9	

**Including 50% of Neutral Zone*

Source: Oil & Gas Journal.

Table 4, which aggregates oil reserves by groups of countries, shows that almost two-thirds of the current reserves belong to the thirteen member nations of the Organization of Petroleum Exporting Countries (OPEC). About 13 percent are in the Centrally Planned Economies (CPE) of the U.S.S.R., People's Republic of China, Eastern Europe, and Southeast Asia. Only 10 percent are estimated to be in the principal industrial nations which form the Organization for Economic Co-Operation and Development (OECD) and are the world's major energy consumers. The other 12 percent are in the rest of the world, which means all the developing countries outside OPEC, most of which—with the principal exception of Mexico—must import the bulk of their energy supplies.

Table 4

Estimated Proved Crude Oil Reserves By Groups of Countries**

(Billions of barrels)

	1/1/82	%	1/1/77	%	1/1/72	%
OPEC	439.0	65	404.2	67	438.7	69
CPE	85.9	13	101.1	17	98.5	16
OECD	63.9	10	64.0	11	63.7	10
ALL OTHERS	81.9	12	29.7	5	31.0	5
TOTAL	670.7	100	599.0	100	631.9	100

Source: Oil & Gas Journal.

**Country Groupings:

OPEC—Algeria, Ecuador, Gabon, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, United Arab Emirates, Venezuela (the Neutral Zone reserves, shared 50/50 by Kuwait and Saudi Arabia, are also included).

CPE—Union of Soviet Socialist Republics, People's Republic of China, Eastern Europe, Cuba, Mongolia, North Korea, Viet Nam, Yugoslavia, Laos, and Kampuchea.

OECD—Australia, Austria, Belgium, Canada, Denmark, Finland, France, Greece, Iceland, Irish Republic, Italy, Japan, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States, and West Germany

Table 5

Estimated Proved Natural Gas Reserves of Leading Countries

(Trillions of cubic feet)

Rank	Country	1/1/82	1/1/77	(Rank)	1/1/72	(Rank)
1	U.S.S.R.	1160	918	(1)	546	(1)
2	Iran	484	330	(2)	200	(3)
3	U.S.	198	220	(3)	270	(2)
4	Algeria	131	126	(4)	107	(4)
5	Saudi Arabia*	118	66	(5)	56	(7)
6	Canada	90	56	(7)	54	(6)
7	Mexico	75	12	(22)	12	(17)
8	Qatar	60	28	(13)	8	(20)
9	Netherlands	56	62	(6)	83	(5)
10	Norway	49	19	(19)	10	(18)
11	Venezuela	47	41	(9)	25	(12)
12	Nigeria	41	44	(8)	40	(8)
13	Kuwait*	35	34	(10)	35	(10)
14	Indonesia	27	24	(17)	5	(33)
15	Iraq	27	27	(14)	22	(14)
	Top 15	2598	2007		1473	
	All others	313	297		252	
	World Total	2911	2304		1725	

**Including 50% of Neutral Zone*

Source: Oil & Gas Journal.

Proved gas reserves, shown in Tables 5 and 6, also are distributed unevenly, but the list of principal countries shows different rankings and includes four which were not among the top fifteen in oil. The U.S.S.R. leads with 40 percent of the world's total, followed by Iran, the U.S., Algeria, and Saudi Arabia. These first five account for 72 percent; and the top fifteen, 89 percent.

OPEC, led by Iran, has 35 percent of the world's proved gas reserves. The Centrally Planned Economies, mainly the U.S.S.R., have 41 percent. The OECD group has about 16 percent, which is considerably more than its share of oil and reflects the significant reserves of the U.S. and the Netherlands. The remaining 8 percent of proved gas reserves are in the rest of the world, again led by Mexico.

Distribution of Undiscovered Potential

Projections of undiscovered potential, the most speculative figure of all, vary from 1,000 to 2,500 billion barrels oil equivalent.

The petroleum industry's first century has amply demonstrated how unevenly the known hydrocarbon deposits are distributed around the world. Of the 160 basins so far found to be productive, only 25 have contained more than the equivalent of 10 billion barrels of oil (about the size of the Prudhoe Bay field on the Alaskan North Slope). Nevertheless, those 25 basins contain more than 85 percent of all the hydrocarbons discovered in the world to date. Furthermore, only six of these basins have reserves in excess of 50 billion barrels—and account for 65 percent of the total petroleum discovered so far. And, finally, just one basin, the Arabian/Persian Gulf, contains 40 percent of all the petroleum found to date.

Most experts, therefore, expect that an uneven distribution pattern will apply to the 440 basins which have not yet been demonstrated to contain significant amounts of oil or gas. They estimate that while a fair number of these may eventually turn out to be productive, no more than a dozen or so are likely to contain the equivalent of 10 billion barrels or more of oil. And of those, no more than two or three are expected to have the equivalent of 50 billion barrels of recoverable oil. The consensus, moreover, is that it is unlikely the unexplored basins in the world will rival the richness of the Arabian/ Persian Gulf.

Despite all the technical advances made in exploration over the years, the petroleum industry is still unable to determine which of the remaining prospects will contain the major oil and gas fields of the future. The only way to determine this is the time-proven method: by drilling exploration wells. Some geologically promising spots may turn out to be unproductive, while others that appear less promising may yield hydrocarbons in abundance. To illustrate, one need look no farther than the eastern part of the U.S. Gulf of Mexico, which looked promising but turned out to be dry, or the Reforma area of Mexico, which had lain unrecognized and untested for years but which has now turned out to contain a large part of Mexico's currently estimated 57 billion barrel oil reserve. The one sure thing is that until the drill bit chews far into the earth, reserves estimates all are basically guesswork.

Table 6

Estimated Proved Natural Gas Reserves By Groups of Countries **

(Trillions of cubic feet)

	1/1/82	*%*	*1/1/77*	*%*	*1/1/72*	*%*
OPEC	1022	35	783	34	554	32
CPE	1195	41	953	41	558	32
OECD	466	16	460	20	518	30
ALL OTHERS	228	8	108	5	95	6
TOTAL	2911	100	2304	100	1725	100

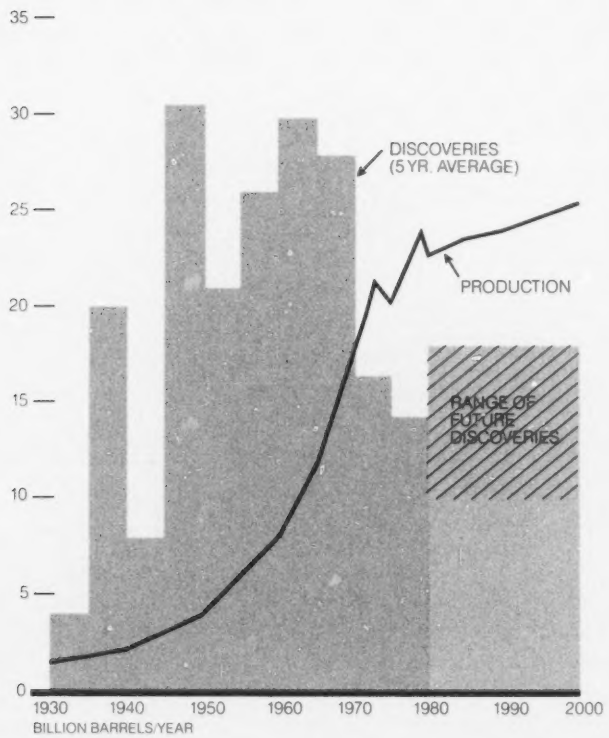
Source: Oil & Gas Journal.

Outlook for Discovery Rates

In the quarter century before 1970, substantial oil finds, principally in the Middle East, raised the world's annual rate of discoveries to an average of 20 to 30 billion barrels (oil discovery and production trends are pictured in Figure 6). As production rates were relatively low, these exploration successes led to a build-up in the inventory of discovered reserves. By the early 1970's, however, the situation had changed. Discoveries had declined to an annual average of about 15 billion barrels. This, coupled with continuously rising production rates, caused the inventory of discovered reserves to begin to decline.

Figure 6*

World Oil Discoveries



* *In these charts, all ultimately recoverable oil and gas are credited to the year in which each field is originally discovered. For any given year, the totals shown on these charts will differ from the "reserve additions" figures for that year, which are sometimes quoted in the press. This is because the latter include reserves for fields discovered in earlier years (not just those for the year in question) and are "proved" reserves only (rather than estimated ultimate recoveries).*

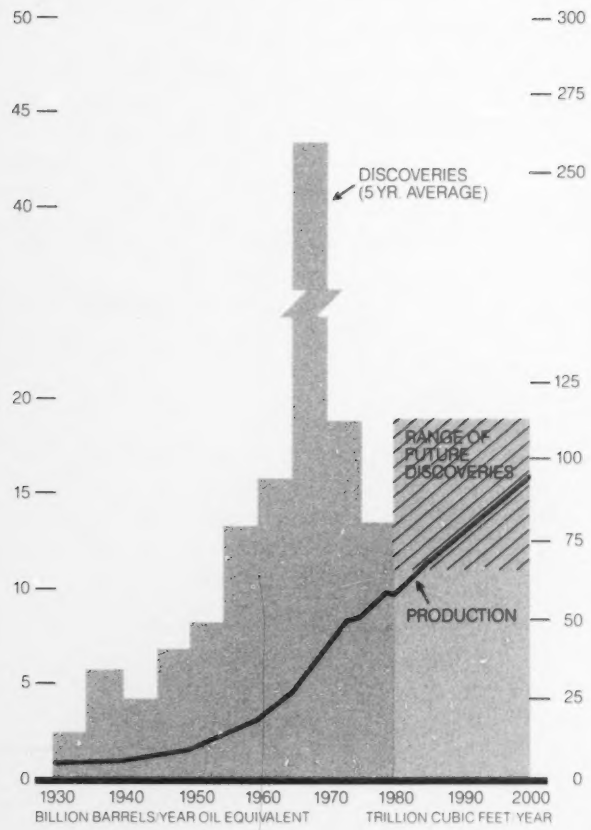
Even assuming continued active exploration efforts, something like the lower overall discovery rates of the last decade is expected to persist in the future. If world oil consumption holds steady or increases slightly in the years ahead, the decline in the inventory of discovered oil reserves is likely to continue. As a result, oil production eventually will reach a plateau—probably sometime early in the next century—and then begin to drop.

Historical information about gas discovery and consumption rates is not as complete and accurate as for oil, and projections for the future are more uncertain. However, present data indicate that, in contrast to oil, the gas discovery rate still exceeds the gas production rate (as depicted in Figure 7). Moreover, the world is expected to go on building an inventory of discovered gas reserves, even with projected steady increases in gas production, and is not expected to begin liquidating that inventory for some years. Therefore, gas production probably will not reach its peak until well into the 21st century.

Predictions are always risky, but petroleum industry experts are fairly certain about some aspects of the discovery outlook. Finding and developing the world's as yet undiscovered oil and gas resources will be progressively more difficult and costly. The number of unexplored areas where there are chances of finding large fields is steadily diminishing. Furthermore, many of the more promising of these are either in remote, undeveloped locations or involve exceptionally harsh operating environments, such as deep water or the cold of the polar regions. In such places, exploration and production operations are sure to be technologically demanding and the development of new fields will require long lead times.

Figure 7*

World Gas Discoveries



Experience has shown that the largest discoveries in a basin are usually made first and that the sizes of new fields generally decrease as exploration progresses in that basin. This means that in those areas where production already exists, the fields now remaining to be discovered are likely to be smaller, on average, than past discoveries.

What all of this signifies is that despite anticipated high levels of exploration effort, the world's total remaining discovered resources are expected to decline with time. Eventually—sooner for oil, a little later for gas—there simply won't be enough oil or gas reserves in the world to support further growth and, inevitably, production will begin to decline. When this will happen depends on how rapidly existing resources are produced and the rate at which the industry can find and develop new reserves in the future as well as on the costs of alternatives.

Improved recovery methods are already employed in many countries, but the potential for broader application and for technology improvement is substantial. In fact, some experts believe that these techniques could double the recovery from many existing fields.

Improved recovery most often comes into play after natural reservoir pressures have pushed out all of the petroleum they can. That usually is from a fifth to a third of the oil in place and half to three quarters of the gas in gas fields. Sometimes, however, natural and improved recovery methods are employed concurrently. In the case of fields containing very heavy oil—that is, crude oil too viscous to be produced in the normal manner—improved recovery techniques may be the *only* feasible way to extract *any* of the oil or gas.

The initial phase of improved recovery—more commonly known as secondary recovery—involves injecting water or gas to displace more oil. These secondary methods already are very widely employed. For example, about half of U.S. production currently comes from fields where secondary recovery techniques are utilized. However, these processes still leave behind large quantities of oil and gas.

A more advanced form of improved recovery—tertiary—is used to coax out some more of this remaining petroleum. Tertiary recovery usually takes one of three principal forms: thermal, chemical, or miscible. The approach used in a particular situation depends on the nature of the oil, gas, and water in place and on rock characteristics and reservoir parameters. Among the most important factors are the type of oil—light, medium, or heavy—and the reservoir depth and pressure. Generally:

> *Thermal* methods are used in relatively shallow, low pressure reservoirs containing thick, highly viscous oils. The processes, which includes steam injection and in situ combustion, heat the rock and the oil. This reduces oil viscosity and makes it easier for the oil to flow into the producing wells.

>*Chemical* methods are applicable to a wide range of oils and a broad variety of reservoir conditions. The processes include flooding with detergent-like surfactants to wash oil from surfaces in a reservoir and injection of polymers which, by "thickening" the water, make it more effective in pushing oil toward producing wells.

> *Miscible* methods—best suited to medium and light oils in fairly deep, medium to high pressure reservoirs—include solvent flooding and the injection of carbon dioxide or nitrogen. The objective is to achieve a complete mixture of reservoir fluids and injected fluids, which improves flow characteristics and makes it easier to displace the oil.

The potential attractiveness of these methods has been recognized for a long time. Now, after many years of laboratory experiments and pilot tests, a few commercial-scale tertiary projects are in operation, mostly in the U.S. The slow pace of adoption reflects three things:

> First, there have been, and continue to be, significant technical problems. Some of these problems are related to the reservoir fluids and rocks, others to the injected fluids, and still others to surface environmental issues.

> Second, the costs—both the initial outlays for facilities and chemicals and the subsequent operating expenses—have been, and still are, very high. Most tertiary projects were not attractive before the increases in oil and gas prices of recent years.

> Third, because of the very large initial outlays and significant technical risks, each project must be very carefully studied, planned, and designed. Technical manpower requirements also place limits on the rate at which new projects can be started up.

Some experts think that something like 2,000-4,000 billion barrels oil equivalent would be left in the ground—lost forever—when the existing fields can no longer be produced if it were not for improved recovery efforts (both secondary and tertiary). For the Middle East *alone*, the estimate has ranged from 1,000 to 2,000 billion barrels.

Future improved recovery programs, many of them utilizing still-emerging technologies, are expected to further increase the percentages of the in-place hydrocarbons that can eventually be produced. Just how much is uncertain but the range of resource base figures in Table 1 suggests that the industry is anticipating average recoveries of around 50 percent for oil and over 75 percent for gas. This, in turn, means that perhaps as much as a sixth of the current estimate of the world's remaining discovered resources is attributed to tertiary recovery techniques.

Other Hydrocarbon Resources

The crude oil and natural gas resources referred to in this booklet are mostly what are termed "conventional hydrocarbons"—that is, naturally occurring fluids existing in the kinds of reservoirs that the petroleum industry is accustomed to. However, there are other sources of hydrocarbon energy which may be called "unconventional"—either because of their chemical makeup or because of the places where they are found. The unconventional sources most likely to be exploited over the balance of this century are:

> Synthetic oil, obtained from the kerogen (an insoluble organic substance which can be converted into a hydrocarbon) found in oil shales.

> Synthetic oil and gas, derived from coal.

> Crude oil which is extremely viscous to semi-solid, deposited in sandstone rocks (oil sands or tar sands, containing bitumen or very heavy oil).

> Natural gas trapped in extremely low permeability rocks (tight gas sands).

The unconventional source farthest from current exploitation is natural gas which is trapped subsurface in:

> Extremely deep sedimentary rocks (30,000-50,000 ft.).

> Geopressured sediments (dissolved in water).

> Shallow shale beds (especially Devonian shales).

> Coal seams.

> Solid hydrates in arctic regions and ocean areas.

Except for limited amounts of very heavy oil and some of the gas in tight sands, none of these other hydrocarbon resources is included in the resource estimates discussed previously. While volume claims for several of them are mind-boggling, there are, unfortunately, few hard data on these resources. Some involve staggering technological, environmental, and economic problems. In fact, it may take more energy to recover some of these resources than can be obtained from them. Others could be even more costly to exploit than future large-scale sources of renewable energy.

5 Summary

No one knows for sure the amounts of oil and gas that remain in the earth. Major uncertainties inhere both in resource estimation techniques and in the economic factors governing reserves. The most recent estimates place the world's total resource base between 3,000 and 5,000 billion barrels oil equivalent, of which nearly a third (1,000-1,200 billion barrels) is now considered proved reserves—that is, oil and gas producible in today's circumstances. Since the world's annual oil and gas consumption is expected to average 30-40 billion barrels oil equivalent per year over the next couple of decades, there are sufficient reserves at present. However, by the end of this century there won't be enough reserves to permit production at levels now foreseen, unless substantial quantities of new oil and gas are discovered in the interim.

An understanding of the concepts and terms used in analyzing the petroleum resource base and reasoned estimates of its components are important for public policy. They enable governments and the public to place information about new discoveries in perspective, and they help to insure the timely discovery and development of additional supplies of oil and gas. In addition, they provide a background against which to plan the development of alternative energy sources—both those, such as coal, that can be important in the near term and those, such as synthetic fuels and the renewable forms of energy, on which the world will increasingly depend over the long run.